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(54) Title: METHOD AND APPARATUS FOR DETERMINING PHYSICAL VARIABLES OF A SLURRY OR LIQUID

(57) Abstract

A non-positive displacement pump (such as a centrifugal pump) is used to determine physical variables of a slurry (such as medium consistency paper pulp) or liquid. In essence by utilizing information from the manufacturer of the pump, and by connecting up the pump to a device for determining the power supplied to the pump to effect pumping, and a device for determining the pressure difference between inlet and outlet piping, the pump essentially may be used as a sensor for determining the density, solids consistency, volume rate of flow, and/or gas content of the liquid or slurry being pumped.

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METHOD AND APPARATUS FOR DETERMINING PHYSICAL VARIABLES OF A SLURRY OR LIQUID

BACKGROUND AND SUMMARY OF THE INVENTION

The present invention relates to a method and an apparatus for determiming physical variables of a slurry or liquid in industrial applications. Additionally, the invention relates to the use of pumps, preferably centrifugal or propeller pumps, and especially to novel ways of utilizing the information available to the designer and manufacturer of centrifugal or propeller pumps in industrial applications, i.e. in mill scale.

A centrifugal pump, as well as a propeller pump, has been considered by an ordinary user as a piece of equipment which has remained the same for decades. The user purchases a centrifugal or propeller pump for his purpose, installs the pump and starts using the pump. The only expectations he may have are that the pump could remain operative slightly longer than the previous one due to somewhat improved materials, sealings and bearings and that the power input could be slightly lower due to slightly improved efficiency which would be based on more accurate manufacture and improved mechanical components. Yet, he is basically satisfied with the pump and does not expect any great improvements.

Simultaneously, the user is faced with problems, not directly related to the pump itself but to the entire pumping operation. The user would like to have information on the medium to be pumped, for instance, the volume rate of flow, the density, the concentration, the gas content, etc. The more important it would be to have the information the more difficult it is to find out the information, in practice. Normally, the user have to purchase several different instruments to determine the above mentioned variables. It is also a fact that the measuring devices are, mainly due to their complex instrumentation, very expensive, oftentimes more expensive than the pump doing the actual work.

The problems which have above been discussed in a more or less abstract manner can be exemplified when considering pumping of a medium consistency slurry, particularly medium consistency cellulose pulp (medium consistency being between about 6 - 18% solids, and more desirably between about 7-15%, e.g, about 8-12%). The cellulose pulp slurry contains at least fibers, fiber bundles, and water, oftentimes also gas and/or other chemicals and/or other solids. Especially with this kind of a medium it is difficult to determine the exact consistency and volume rate of flow, for example. Conventional proposals for determining these variables have proven to be less reliable than desired.

In the following the pumping operation as a whole is studied in more detail in order to find out whether the information the pump designer and the manufacturer have could be used for helping the user to receive the information he needs concerning the medium to be pumped. In the following it has been discussed of centrifugal pumps only though, as already mentioned above also so called propeller pumps could be utilized in a similar manner. In other words, the following theory may be utilized in connection with pumps other than so called positive displacement pumps.

A centrifugal pump is a flow machine in which the specific enthalpy of the medium flowing through the pump is increased by means of the power consumed by the pump. This phenomenon is illustrated by the characteristic curves shown in Fig. 1. These so called pump curves have been normally plotted for a certain rotational speed i.e. the nominal speed. In other words, when measuring or determining the power consumption or power input (P), the pressure head (H, given in meters) or the total differential head (the differential therebetween has been explained later on) and the efficiency (η) the rotational speed of the pump has been maintained constant. Normally the above variables have been determined as a function of the volume rate of flow of the pump. In other words, if one knows the power input he can find out from the pump characteristic curves the volume rate of flow and the pressure head as well as the efficiency of the pump. Thus, it is a

normal practice to stop examining the pump curves at this point. What this means in practice is that the use of pressure head (H, given in meters) in all pump curves blurs the fact that if the pump curves were plotted including enthalpy (h given in kJ/kg) it would be a question of much more than the number of meters the pump is able to lift the medium to be pumped.

A much more exact approach could be done if the term enthalpy (h) would be used in place of total differential head (H) in the characteristic curves of a pump. In such a case the change in the total specific enthalpy of the flow medium could be calculated by using an equation:

$$\Delta h=\frac{p_2-p_1}{\rho}+\frac{z_2-z_1}{g}+\frac{w_2^2-w_1^2}{2} \qquad (1)$$

in which the subindex '$_1$' recites to a variable measured upstream of a pump and subindex '$_2$' to a variable measured downstream of a pump. In the above equation p is the pressure, z is the height of the point of the pressure measurement, g is gravitational acceleration, ρ is the density of the flow medium and w is the flow velocity of the flow medium at the point of the pressure measurement. The differential between pressure head (H) and enthalpy (h) is such that enthalpy is a sum of pressure head (the first, "p" term in eq. 1), so called geodesic head (the second, "z" term in eq. 1) and velocity head (the third, "w" term in eq, 1) all divided by gravitational acceleration (g)(see also eq. 3).

Next, the efficiency of the pump is calculated from equation

$$\eta=\Delta h\cdot\rho\cdot\frac{Q}{P} \qquad (2)$$

And, the correlation between the change in enthalpy Δh and total differential head H is given by equation

$$H=\frac{\Delta h}{g} \qquad (3)$$

However, the theory concerning the operation and use of centrifugal pumps goes still further. It is known that when the rotational speed of a pump is changed also the numerical values of the variables in the characteristic curves of the pump change. In other words, one could plot different pump curves by means of running the pump test with different rotational speeds. However, there is an easier way to find out the effect of the changes in rotational speed in the pump curves. It is a generally accepted fact that, especially when it is a question of Newtonian liquids, and when the change in rotational speed is not large the so called law of kinematic similarity holds true with substantial accuracy, in other words

$$Q_a=Q_b\cdot\frac{n_a}{n_b}$$

$$\Delta h_a=\Delta h_b\cdot\left(\frac{n_a}{n_b}\right)^2 \qquad (4)$$

$$P_a=P_b\cdot\left(\frac{n_a}{n_b}\right)^3$$

In the above equations subindex "a" refers to a situation where the rotational speed is n_a and subindex "b" to a situation where the rotational speed is n_b.

The above group of equations (4) makes it possible to determine the volume rate of flow, the specific enthalpy and the power input in a situation where the pump is rotating at another speed than where the characteristic curves were

determined.

It is also known to determine, or measure, the volume rate of flow when the pressure differential $p_2 - p_1$ and/or the power input P is known. In certain cases, i.e. where the terms containing Δz (height differential) and Δw (flow velocity differential) in equation (1) are identically equal to 0 the total differential head H is given by using equation (3) whereby substituting δh from equation (1) therein gives

$$H = \frac{p_2 - p_1}{\rho \cdot g}$$

(5)

provided that the density ρ of a flow medium is known.

In accordance with Fig. 2 and using the published characteristic curves of a pump where the head H of a pump and the power input P is given as a function of volume rate of flow Q one may have an estimate for the volume rate of flow Q. If for instance the differential between the squares of the flow velocities ("w" term in equation (1)) is not 0 one may reach the solution by using an iterative approach. The values marked with superscript "*" are measured values for the head in accordance with equation (5). In Fig. 2 there has been illustrated how the erroneous values either in the measurement or in the characteristic curve may lead to two different values as an estimate for the volume rate of flow, $Q' = Q_H'$ or $Q' = Q_P'$. In this kind of a case, if no other way to solve the problem exists an average value

$$Q' = \frac{Q_H' + Q_P'}{2}$$

may be used.

It is only up to this point that conventional pump characteristic curves have been used so far. For instance, it has been taken for granted that the density of the medium to be pumped is known. However, when it is a question of an medium consistency pulp changes in both the consistency and gas content have an effect on the density. However, this problem has been overcome by the invention because of a large amount of empirical data that has been gathered from hundreds of test runs that can accurately and reliably determine these values from other values that are easily and reliably measured. For each pump type and size the manufacturer can easily plot graphs that have been developed from doing hundreds of tests which show the correlation between the pressure differential and volume rate of flow, and the power input and volume rate of flow, for a number of different consistencies (see Figs. 4a and 4b) and for a number of different gas contents (see Figs. 6a and 6b). In the utilization of conventional pumps for pumping medium consistency pulp, such as fluidizing centrifugal pumps sold under the trademark MC® by Ahlstrom Pumps, Inc. of Easley, South Carolina, U.S.A. and Ahlstrom Pumps Corporation of Karhula, Finland, it is possible to readily measure the power input to the pump (power consumption) and also the pressure differential over (pressure head of) the pump. The power input may be determined in several different ways. A simple way is to monitor the power the drive unit takes from the electrical network and since the efficiency of the drive unit is known calculate the power taken by the pump itself. Another way is to mount a torque sensor on the shaft and monitor both the torque and the rotational speed of the shaft. In other words, the power input may be determined in a manner known per se. Utilizing this information collected in a manner described above in, for instance, a computer, and using standard formulas based upon this empirical data, it is possible to easily automatically calculate one or both of the volume rate of flow and the consistency as well as the density.

According to one aspect of the present invention a method of determining physical variables of a slurry or liquid in industrial applications using a radial flow or axial flow pump, comprises the steps of:

(1) performing test runs with said pump for receiving information on the operation of the pump as a function of at least one of the density of the slurry or liquid, the solids consistency of the slurry or liquid and the gas content of the slurry or liquid, said information including at least two of the power input P, the volume rate of flow Q of the slurry or liquid, the rotational speed n of the pump, the pressure head H of the pump, and the efficiency η of the pump,

(2) processing said received information with the data fed into the test system i.e. with at least one of the density of the slurry or liquid, the consistency of the slurry or liquid and the gas content of the slurry or liquid;

(3) providing a mill scale installation using a similar pump as the pump in step 1) with said processed information from step 2);

(a) supplying power to the pump to pump the slurry or liquid through the pump in a pathway in which there is a pressure differential between first and second points in the pathway;

(b) measuring the power supplied to the pump;

(c) measuring the pressure differential between the first and second points in the pathway;

(d) inputting said power and said pressure differential into a computer; and

(e) using said computer, automatically calculating one or several physical variables using at least one of the measured values from steps (b) and (c).

The physical value that was calculated in sub-step (e) may be at least one of the volume rate fo flow, the consistency, the density, and the gas content of the slurry or liquid. Preferably the slurry is medium consistency (i.e. between about 6-18%) pulp. Sub-step (c) may be practiced by measuring the pressure difference on opposite sides of the pump, the first and second points being in the pathway on opposite sides of the pump. Sub-step (e) may be practiced to calculate both the volume rate of flow and the consistency of the pulp at an actual mill scale application.

In step (1), preferably at least two of the power input P, the pressure head H, and the efficiency η of the pump are received as a function of the volume rate of flow. When the liquid or slurry is a slurry, in step (7) the information may be processed so that the consistency is given as a function of both pressure head and volume rate of flow c= c(H,Q), and power input and volume rate of flow c = c(P,Q); the processed information whan illustrated in graphical form may be given as a set uf curves, a curve for each consistency value at desired intervals in both a QH graph and a QP graph. In step (2) the information may be also or alternatively processed so that the gas content is given as a function of both pressure head and volume rate of flow k= k(H,Q), and power input and volume rate of flow k = k(P,Q); and the processed information when illustrated in graphical form may be given as a set af curves, a curve for each gas content value at desired intervals in both a QH graph and QP graph.

In step (2) the information fed into the test system of step (1) as a constant value i.e. at least one of the density of the pumpable slurry or liquid, the consistency of the pumpable slurry or liquid and the gas content of the pumpable slurry or liquid and as a function of which the test runs are performed and the information received as results of the test runs i.e. the measured values for at least some of the power input of the pump, the volume rate of flow of the slurry or liquid, the efficiency of the pump, the rotational speed of the pump, and the pressure head are processed in such a manner that the processed information is readily usable in mill scale applications. The processing may mean, e.g. forming of sets of curves e.g. characteristic curves for each pump type and size showing the needed correlations between different variables. The physical variables may then be calculated by a certain type of software. The processing may also mean forming of a mathematical model for the pumping whereby another type of software may be used for calculating the physical variables.

Sub-step (d) may be further practiced by inputting at least two of enthalpy, power input, and efficiency of the pump into the computer. Alternatively

or in addition sub step (a) may be further practiced by inputting into the computer each of the constant consistency curves c = c(Q,H) received from the test runs of step (1) as a function of volume rate of flow and pressure head. Sub-step (d) may be alternatively or further practiced by inputting each of the constant consistency curves c = c(Q,h) received from the test runs of step (1) as a function af volume rate of flow and enthalpy into the computer. Sub-step(d) may be alternatively or additionally further practiced by creating a mathematical function for each consistency curve. Sub-step (d) may be alternatively or additionally be practiced by inputting each of the constant gas content curves k = k(Q,H) received from the test runs of step (1) as a function of volume rate of flow and pressure head into the computer. Sub-step (d) may be alternatively or additionally further practiced by inputting each of the constant gas content curves k = k(Q,h) received from the test runs of step (1) as a function of volume rate of flow and enthalpy into the computer. Sub-step (d) may be further practiced by creating a mathematical formula for each gas content curve.

The calculations for sub-step (e) may be used to control operation of the pump, to reconfigure it or surrounding equipment, to change (automatically or manually) one or more physical parameters of the liquid or slurry, or to perform a number of other functions.

According to one aspect of the present invention an apparatus for determining at least one physical variable of a slurry or liquid comprises a pump housing with an inlet channel forming part of a so called inlet piping, an outlet channel forming part of a so called outlet piping and an impeller arranged within said housing and attached to a shaft rotatably connected to drive means. Said pump inlet piping and said pump outlet piping are provided with means for determining a pressure differential between said pipings. Said drive means are provided with means for determining the power supplied to the pump to effect pumping of the slurry or liquid thereby. A computer is connected to the pressure differential and power determining means to use information supplied thereby to calculate said at

least one physical variable of a slurry or liquid flow.

Said pressure differential determining means may be connected to two points in the flow pathway of which points one is disposed in one of the inlet channel and in the outlet channel. The pressure difference determining means may alternatively be connected to two points, of which one is disposed in the inlet channel and the other in the outlet channel. The pressure difference determining means may be preferably connected to two pressure sensors of which at least one is disposed in one of the inlet channel and the outlet channel. The pump is preferably a non- positive displacement pump, such as a centrifugal pump (e.g. a fluidizing centrifugal pump, used for pumping medium consistency pulp).

According to another aspect of the present invention an apparatus for determining physical variables of a slurry or liquid comprises a non-positive displacement pump housing with an inlet channel forming part of a so called inlet piping, an outlet channel forming part of a so called outlet piping and an impeller arranged within said housing and attached to a shaft. Said apparatus comprises further means for determining a pressure differential between said pump inlet channel and said pump outlet channel. A drive may be an electric motor and include means for determining the power used for pumping the pulp. A computer may be connected to the pressure difference determining means and to the power determining means to use information supplied thereby to calculate the physical variables.

The invention also relates to a method of operating a non-positive displacement pump pumping a liquid or slurry, comprising the steps of using the non-positive displacement pump as a sensor for determining the density, solids consistency, volume rate of flow, and/or gas content of the liquid or slurry being pumped.

It is the primary object of the present invention to provide for

optimum operation or utilization of a pump, and an apparatus which also allows optimization of the pump operation. This and other objects of the invention will become clear from an inspection of the detailed description of the invention and from the appended claims.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a schematic graphical representation illustrating the correlation between the pressure head, power input, the volume rate of flow and the efficiency for a centrifugal pump;

Figure 2 is a schematic graphical representation for the same pump as in Figure 1 showing the way how volume rate of flow is determined when the power input and the pressure head is known;

Figure 3 is a schematic representation of a preferred novel way of defining the volume rate of flow of a centrifugal pump using the information received from trial runs of a centrifugal pump;

Figures 4a and 4b are schematic graphical representations for the same pump as in Figure 1 showing the correlation between the pulp consistency, the power input, the pressure head and the volume rate of flow; and

Figures 5a and 5b are schematic graphical representations showing a novel way of determining pulp consistency when the pressure head and the power input are known,

Figures 6a and 6b are schematic graphical representations for the same pump as in Figure 1 showing the correlation between the gas content of the pulp, the pressure head, the power input and the volume rate of flow; and

Figure 7 is a schematic representation of exemplary apparatus according to the invention used in the practice of the exemplary method according to the invention.

DETAILED DESCRIPTION OF THE DRAWINGS

As it has been explained above in connection with the prior art the density of the flow medium has to be either known or has to be measured in order to be able to use the prior art methods. However, when the density of the slurry or liquid to be pumped may change and when it has not been measured one could proceed as follows. There are two unknown variables, volume rate of flow (Q) and density (ρ). Therefore both $p_2 - p_1$ and power input P have to be measured. After having measured the both variables the problem can be solved and both density and volume rate of flow be determined as soon as there are two independent equations. The equations which could be used are equation (5), the simplified equation for the head of a pump and equation (2) defining the efficiency of the pump. Applying first definition (3) to equation (5) and then substituting the results to equation (2) gives

$$\frac{P}{p_2 - p_1} = \frac{Q}{\eta} \qquad (6)$$

In accordance with Fig. 1 the efficiency η is a function of volume rate of flow Q, $\eta = \eta(Q)$. Equation (6) is diagrammatically illustrated in Fig. 3. The ratio $Q/\eta(Q)$ may be determined in connection with, for instance, the test run of a pump. The measured values P^*, p_2^* and p_1^* give in accordance with Fig. 3 a value Q' for volume rate of flow. An estimate for the density is received by means of applying the curve h for the head (H) of the pump (corresponding to specific enthalpy) of Fig. 1. When the volume rate of flow is Q'

$$\frac{p_2{*} - p_1{*}}{\rho{*}} = \Delta h(Q') \qquad (7)$$

thereby solving the equation gives

$$\rho{*} = \frac{p_2{*} - p_1{*}}{\Delta h(Q')} \qquad (8)$$

In other words, measuring both the pressure differential and the power input and using the above described method both the volume rate of flow and the density can be solved for the slurry or liquid. The result is that the user of a pump has at his/her disposal a combined sensor for both volume rate of flow and density.

The conventional pressure sensors (e.g. diaphragm, pisto, piezoelectric, or other conventional type) for determining the pressure differential are preferably positioned in the pump housing. Though it may seem an obvious choice to position the pressure sensors in the pipe line upstream (the inlet conduit) and downstream (the outlet conduit) of the pump that should not be done. With such an approach one would lose the accuracy of the measurements as the measured values would hardly correspond to those received in pump manufacturer's own test runs whereby the pump manufacturer's data which could otherwise be used, in accordance with our invention, loses it accuracy. Merely the change in positioning of the sensors would lead to remarkable errors in the final results. The inlet and outlet conduits in mill applications are hardly ever identical to those of the pump manufacturer's test stations. Naturally, if the sensors are, for some reason, to be positioned outside the pump itself it is highly desirable to design the inlet and outlet conduit as exactly as possible in accordance with the pump manufacturer's instructions. Another fact speaking in favour of the positioning of the sensors in the pump housing is the possibility to simplify the overall structure of the pipe line in the nearhood of the pump. For instance, it would be possible to fasten a valve directly to the pump outlet without a short piece of pipe with the pressure sensor arranged between the pump outlet and the valve.

There are other variables having an effect on pumping process other than the density of the flow slurry or liquid. The most important characterising variable in MC® pumping is the consistency of the pulp. Consistency, or solids consistency, being understood as the relative amount of solids (particularly fibers) in the fiber-water mixture (slurry). For the sake of simplicity, the easiest way to

study the situattion is by leaving other variables (like density and gas content) out of the evaluation. Figs. 4a and 4b illustrate the correlation of the consistency (c) to the characteristic curves of an MC® pump. The curves have been plotted from tests where, in each test, the consistency was maintained constant and, for instance, the volume rate of flow was changed and both the power input and the pressure head was measured. In this way, the desired accuracy of the measuments defined the number of test series driven. For instance, if the desired consistency interval is 0.5 % and the consistency range from 6 to 16 % there are 21 test series to run to have 21 consistency curves in both QH- and QP-graphs. Between each series of tests the consistency of the pulp was changed by the desired interval (e.g. 0.5%). The subindexes '$_1$','$_2$' and '$_3$' in Figs. 4a and 4b show the direction of the increase in consistency - the higher the subindex the higher is the consistency. For example, for a relatively low value of medium consistency, such as about 7%, the graph c_1 indicates the relationship, while for a relatively higher consistency, e.g. about 14%, the graph c_4 indicates the relationship, with a large number of graphs c_1 - c_n, providing empirical data for a given pump, type and size input into a computer. In other words, each of the curves in Figs. 4a $H = H(Q,c)$ and 4b $P = P(Q,c)$ have been plotted at constant consistency. These curves may be fed into a computer's memory using conventional techniques and it is a simple and common practice for a computer programmer to develop a program that solves the desired values.

For determining the consistency the user of a pump is able to make the following two measurements, again, $p_2^* - p_1^*$ (corresponding to pressure head H) and P^*. The graphic solution of the problem i.e. for determining the consistency with the help of the volume rate of flow Q^* is illustrated in Figs. 5a and 5b. Positioning the pressure differential i.e. the pressure head H^* in Fig. 5a gives a first horizontal line, parallel to x-axis, and positioning the power input P^* in Fig. 5b gives a second horizontal line. The consistency in question is found when a ruler is placed in a vertical position on Figs. 5a and 5b and moving it across the consistency curves until the H^* line and P^* line intersect the ruler on consistency curves $c_H = c_P$ giving the desired consistency c^*.

The solution can also be calculated numerically as follows. First functions H and P are created, for instance by feeding the values of the curves like the one shown in Figs. 5a and 5b into a computer program which is programmed to find the equations of the type shown in (9) giving the inputted values

$$H=H(Q,c)$$
$$P=P(Q,c) \tag{9}$$

For the sake of simplicity, the most simple feasible functioning model could be of linear form as follows

$$H=a_0+a_1\cdot Q+a_2\cdot c$$
$$P=b_0+b_1\cdot Q+b_2\cdot c \tag{10}$$

And, substituting H = H* and P = P* gives

$$Q'=\frac{b_2\cdot(H*-a_0)-a_2\cdot(P*-b_0)}{a_1b_2-a_2b_1}$$
$$c'=\frac{a_1\cdot(P*-b_0)-b_1\cdot(H*-a_0)}{a_1\cdot b_2-a_2\cdot b_1} \tag{11}$$

However, since the shape of the curves in Figs. 4a and 4b is typically non-linear it should be understood that the linear model is too simple. However, the above shows the basic principle of determining the consistency c.

In any case the above described method of determining volume rate of flow and consistency is based on the pump tests made by the manufacturer. In other words, the present invention relates to taking full advantage of the possibilities the pump manufacturer has since the manufacturer tests their pumps with regard to all the needed variables. Now, the present invention makes it

possible for the user of the pump to define a number of physical variables just by using the pump itself as a sensor for those variables, for example for volume rate of flow and/or consistency. The above method can be used in all kinds of centrifugal pumps i.e. both pumps for MC® pulp, low consistency pulp and water. Also the method may be applied for determining the gas content, too. In such a case some additional measurements relating to the gas discharge or to the size of the gas bubble at the eye of the pump impeller are needed.

Figs. 6a and 6b illustrate the correlation of the gas content k to the pressure head H and the power input. The curves have been plotted from tests where, in each test, the gas content value was maintained constant and, for instance, the volume rate of flow was changed and both the power input and the pressure head was measured. In this way, the desired accuracy of the measurements defined the number of test series driven. For instance, if the desired gas content interval is 0.5 % and the gas content range from 5 to 20 % there are 31 test series to run to have 31 gas content curves in both QH- and QP-graphs. Between each series of tests the gas content of the pulp was changed by the desired interval, naturally. The subindexes '$_1$','$_2$' and '$_3$' in Figs. 6a and 6b show the direction of the increase in gas content the higher the subindex the higher is the gas content. In other words, each of the curves k_1, k_2 and k_3 in Figs. 6a $H = H(Q,k)$ and 6b $P = P(Q,k)$ have been plotted at constant gas content. The gas content can be defined in a manner similar to the consistency determination.

Figure 7 shows a flow pathway 10, such as, for example only, a standard pulp conduit having an inlet conduit 12 and an outlet conduit 14, between which a pump 16 is provided, preferably a fluidizing MC® pump. The pump 16 has a housing with an inlet channel 18 and an outlet channel 20. The inlet channel 18 of the pump being attached to said inlet conduit 12 forming together so called inlet piping. In a corresponding manner the outlet channel 20 of the pump is attached to the outlet conduit 14 forming together a so called outlet piping. The impeller of the pump 16 is disposed within said housing, attached to a shaft 22 and

driven by a conventional drive, such as an electric motor 24.

The power supplied to the motor 24 to effect rotation of the impeller may be measured utilizing a conventional power measuring device 26. Naturally it is also possible to manually read the power input, process it further, basically manually, and then feed the information manually further e.g. into a conventional computer of any suitable type. In the pathway 10 there is a first point 28 in said inlet piping 12,18 and a second point 30 in said outlet piping 14,20 i.e. on opposite sides of the pump 16 with a conventional pressure differential measuring device 32 disposed in line 34 between the points 28, 30.

There are several options for determining the pressure differential. I.e. there may be two pressure sensors one positioned to point 28 and the other in point 30 whereafter the differential is determined by a processor unit (for instance 32 could be such a unit) or the computer 36 or the differential could even be calculated manually (e.g. using a hand held calculator, slide rule, or pen and paper). There may also be a unit 32 determining the pressure differential directly. In such a case the unit 32 could be connected with two pipes to points 28 and 30 and sense the pressure differential. The data from the measuring devices 26, 32 is fed, either automatically or manually, to a conventional computer 36. Because of the empirical data known from the above discussed figures 1 through 6b which has been input into the computer 36, for each different pump type and size, and because the pump type and size is also input into the computer 36, it is possible to automatically calculate one or both of the volume rate of flow and the solids consistency, or the gas content, or the density, because the variables can be solved in such a manner that there are two equations and two variables, for instance, volume rate of flow (Q) and consistency c (in percent) to be solved.

The means for determining pressure differential may be any suitable conventional device, typically of fluidic, mechanical, electro-mechanical, piezoelectric, or substantially solely electrical, construction, which is capable of

measuring pressure differential. The means 26 for determining the power supplied to the pump 16 to effect pumping of the liquid or slurry may also be of any suitable conventional construction.

The most practical places for the pressure sensing means are believed to be the inlet channel 18 and the outlet channel 20, primarily due to the facts discussed earlier in this description.

It should be, again, kept in mind that the above specification is to be understood as an example only, at least with regard to the discussion concerning centrifugal, or even closer MC® pumps, since the same principle of operation may be used with all pumps except the so called positive displacement pumps. A way to describe the pumps included in this category is to talk about non-positive displacement pumps which would then include at least so called radial flow pumps i.e. centrifugal pumps and helico-centrifugal pumps; and axial flow pumps. It should also be understood that the above specification as well as the appended claims describe the invention in a simplified manner referring more to a way how the invention would be used manually, or graphically. Therefore, it is clear that all ways of utilising the invention by using a computer and special software are within the scope of the invention.

CLAIMS

1. A method of determining physical variables of a pumpable slurry or liquid in industrial applications using a radial flow or axial flow pump, characterized by the steps of:

(1) performing test runs with said pump for receiving information on the operation of the pump as a function of at least one of the density of the pumpable slurry or liquid, the consistency of the pumpable slurry or liquid and the gas content of the pumpable slurry or liquid, said information including at least two of the power input P, the volume rate of flow Q of the pumpable slurry or liquid, the rotational speed n of the pump, the pressure head H of the pump, and the efficiency η of the pump,

(2) processing said received information with the data fed into the test system i.e. with at least one of the density of the pumpable slurry or liquid, the consistency of the pumpable slurry or liquid and the gas content of the pumpable slurry or liquid;

(3) providing a mill scale installation using a similar pump as in step (1) with said processed information from step (2);

(a) supplying power to the pump to pump the pumpable slurry or liquid through the pump in a pathway in which there is a pressure differential between first and second points in the pathway;

(b) measuring the power supplied to the pump in sub-step (a);

(c) measuring the pressure differential between the first and second points in the pathway;

(d) inputting said power and said pressure differential into a computer; and

(e) using said computer, automatically calculating one or several physical variables using at least one of the measured values from steps (b) and (c).

2. A method as recited in claim 1, characterized in that said physical variables calculated in sub-step (e) are at least one of the volume rate of flow, the

consistency, the density and the gas content of the slurry or liquid.

3. A method as recited in claim 1 **characterized** in that the pumpable slurry or liquid is cellulose pulp, preferably so called MC® pulp, i.e. a slurry having a solids content or a consistency between about 6 - 18%.

4. A method as recited in claim 1, 2 or 3 **characterized** in that, in step (1), said at least two of the power input P, the pressure head H and the efficiency η of the pump are received as a function of the volume rate of flow.

5. A method as recited in claim 1, 2, 3 or 4 **characterized** in that, in step (2) the information is processed so that said consistency is given as a function of both pressure head and volume rate of flow c = c(H,Q), and power input and volume rate of flow c = c(P,Q).

6. A method as recited in claim 5 **characterized** in that said processed information, when illustrated in graphical form, is given as a set of curves, a curve for each consistency value at desired intervals both in the QH-graph and in the QP-graph.

7. A method as recited in claim 1, 2, 3 or 4 **characterized** in that, in step (2) the information is processed so that said gas content is given as a function of both pressure head and volume rate of flow k = k(H,Q), and power input and volume rate of flow k = k(P,Q).

8. A method as recited in claim 7 **characterized** in that said processed information, when illustrated in graphical form, is given as a set of curves a curve for each gas content value at desired intervals both in the QH-graph and in the QP-graph.

9. A method as recited in claim 3 **characterized** in that sub-step (e) is

practised to calculate both the volume rate of flow and the consistency of the pulp in actual mill scale application.

10. A method as recited in claim 3 <u>characterized</u> in that sub-step (c) is practised by measuring the pressure differential on opposite sides of the pump, the first and second points being in the pathway on opposite sides of the pump.

11. A method as recited in claim 1 <u>characterized</u> in that sub-step (d) is further practiced by inputting at least two of enthalpy, power input, and efficiency of said pump into the computer.

12. A method as recited in claim 1 <u>characterized</u> in that sub-step (d) is further practiced by inputting each of the constant consistency curves c = c(Q,H) received from manufacturer's test runs as a function of volume rate of flow and pressure head into the computer.

13. A method as recited in claim 1 <u>characterized</u> in that sub-step (d) is further practiced by inputting each of the constant consistency curves c = c(Q,h) received from manufacturer's test runs as a function of volume rate of flow and enthalpy into the computer.

14. A method as recited in claim 12 or 13 <u>characterized</u> in that sub-step (d) is further practiced by creating a mathematical function for each consistency curve.

15. A method as recited in claim 1 <u>characterized</u> in that sub-step (d) is further practiced by inputting each of the constant gas content curves k = k(Q,H) received from the test runs of step (1) as a function of volume rate of flow and pressure head into the computer.

16. A method as recited in claim 1 <u>characterized</u> in that sub-step (d) is

furher practiced by inputting each of the constant gas content curves k = k(Q,h) received from the test runs of step (1) as a function of volume rate of flow and enthalpy into the computer.

17. A method as recited in claim 15 or 16 characterized in that sub-step (d) is further ptactices by creating a mathematical function for each gas content curve.

18. An apparatus for determining physical variables of a slurry or liquid flow comprising: a pump (16) housing with an inlet channel (18) forming part of an inlet piping (12,18), an outlet channel (20) forming part of an outlet piping (20, 14) and an impeller disposed within said housing and attached on a shaft (22) rotatably driven by drive means (24), characterized in that said pump inlet piping (12, 18) and said pump outlet piping (20, 14) is provided with means (32) for determining a pressure differential between said pipings, said drive means (24) being provided with means (26) for determining the power supplied to the pump (16) to effect pumping of the pumpable slurry or liquid thereby; and a computer (36) connected to the pressure differential (32) and power (26) determining means to use information supplied thereby to calculate at least one physical variable of a liquid or slurry flow.

19. An apparatus as recited in claim 18 characterized in that said physical variable is at least one of the volume rate of flow of the pumpable slurry or liquid, the density of the pumpable slurry or liquid, the gas content of said pumpable slurry or liquid and the consistency of the slurry or liquid flowing through the pathway.

20. Apparatus as recited in claim 18 characterized in that said pressure differential determining means (32, 36) is connected to two pressure sensors of which one is disposed in one of said inlet channel (18) and said outlet channel (20).

21. Apparatus as recited in claim 18 characterized in that said pressure differential determining means (32) is connected by means of two pipes to points of which one is disposed in one of said inlet channel (18) and said outlet channel (20).

22. Apparatus as recited in claim 18 characterized in that said pressure differential determining means (32) is connected to two pressure sensors which are disposed in said inlet channel (18) and in said outlet channel (20).

23. Apparatus as recited in claim 18 characterized in that said pressure differential determining means (32) is connected by means of two pipes to points of which one is disposed in said inlet channel (18) and the other in said outlet channel (20).

24. Apparatus as recited in claim 18 characterized in that said pump (16) is a non-positive displacement pump.

25. Apparatus as recited in claim 18 characterized in that said pump (16) is a centrifugal pump.

26. Apparatus as recited in claim 24 characterized in that said centrifugal pump (16) is a medium consistency pump for pumping medium consistency pulp.

27. An apparatus for determining physical variables of a slurry or liquid said apparatus having a non-positive displacement pump (16) housing with an inlet channel (18) forming part of a so called inlet piping (12,18), an outlet channel (20) forming part of a so called outlet piping (20, 14) and an impeller arranged within said housing and attached to a shaft (22), characterized in thet said apparatus comprises means (32) for determining a pressure differential between said pump inlet channel (18) and said pump outlet channel (20).

28. Apparatus as recited in claim 27 characterized in that said pressure differential determining means (32, 36) is connected to two pressure sensors of which one is disposed in said inlet channel (18) and the other in said outlet channel (20).

29. Apparatus as recited in claim 27 characterized in that said pressure differential determining means (32) is connected by means of two pipes to points of which one is disposed in said inlet channel (18) and the other in said outlet channel (20).

30. Apparatus as recited in claim 27 characterized in that said pump (16) is a centrifugal pump.

31. Apparatus as recited in claim 30 characterized in that said centrifugal pump (16) is a medium consistency pump for pumping medium consistency pulp.

32. An apparatus as recited in claim 27 characterized in drive means (24) connected to said shaft (22), said drive means (24) being provided with means (26) for determining the power supplied to the pump (16) to effect pumping of the pumpable slurry or liquid thereby.

33. An apparatus as recited in claim 27 characterized in a computer (36) connected to the pressure differential determining means (32) and power determining means (26) to use information supplied thereby to calculate said physical variables.

34. An apparatus as recited in claim 27 characterized in a computer used for calculating said physical variables from the information received from the pressure differential determining means (32) and power determining means (26).

35. The use of a non-positive displacement pump as a sensor for

determining the density of the pumpable slurry or liquid to be pumped.

36. The use of a non-positive displacement pump as a sensor for determining the consistency of the pumpable slurry or liquid to be pumped.

37. The use of a non-positive displacement pump as a sensor for determining the volume rate of flow of the pumpable slurry or liquid to be pumped.

38. The use of a non-positive displacement pump as a sensor for determining the gas content of the pumpable slurry or liquid to be pumped.

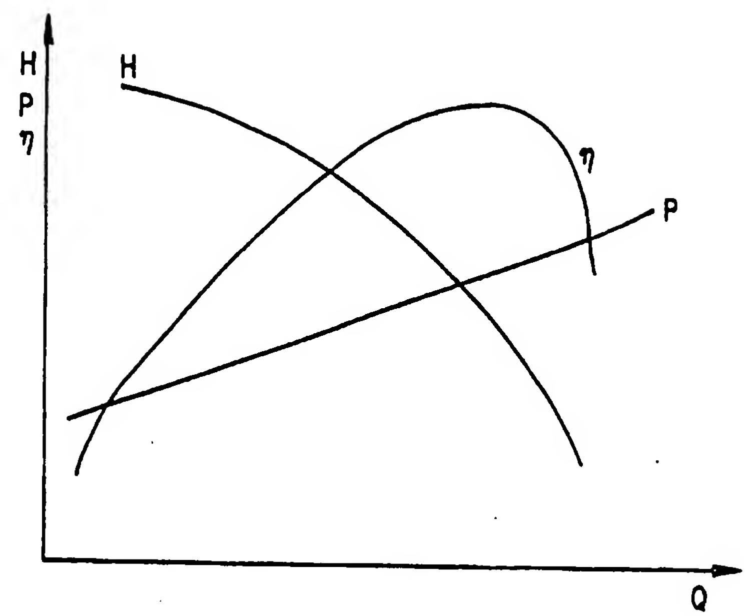

FIG. 1

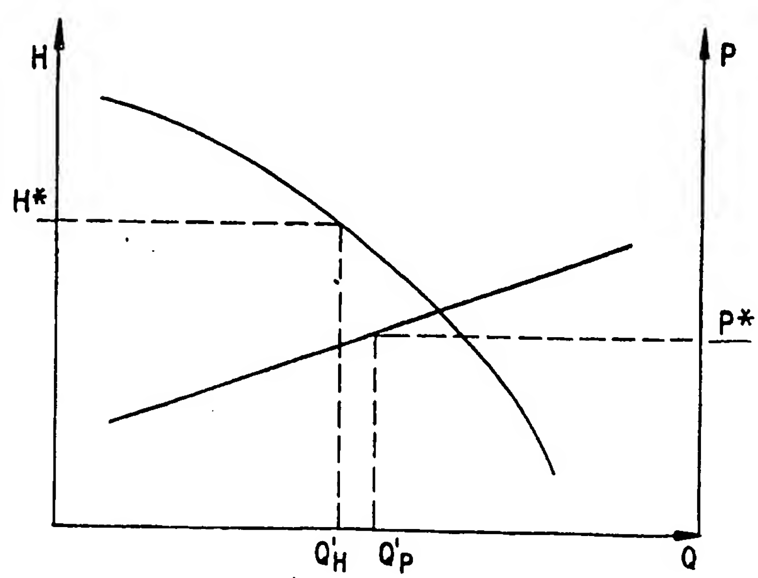

FIG. 2

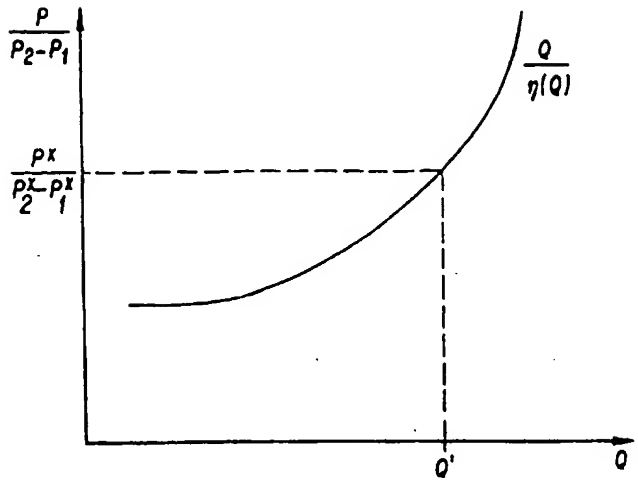

FIG. 3

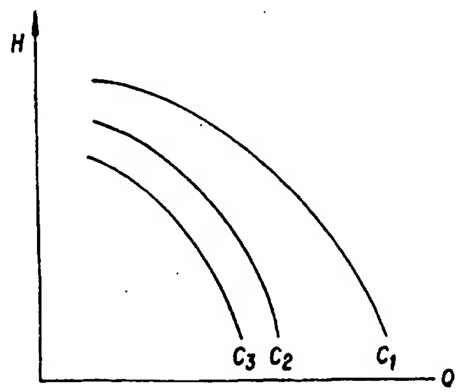

FIG. 4a

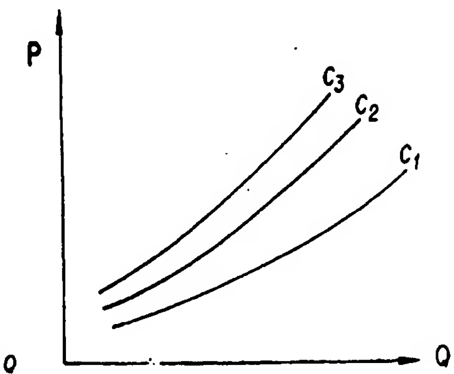

FIG. 4b

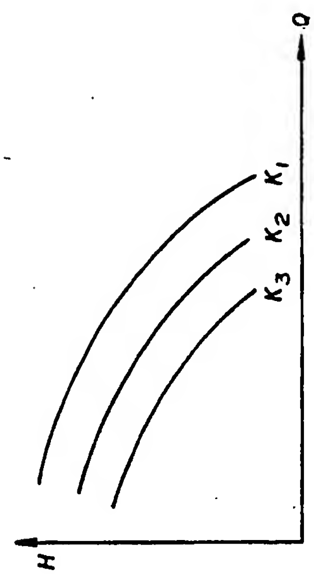

FIG. 6a

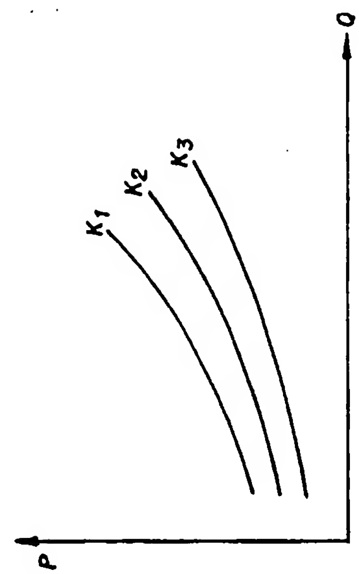

FIG. 6b

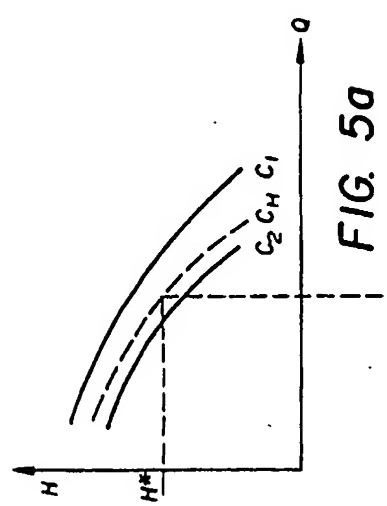

FIG. 5a

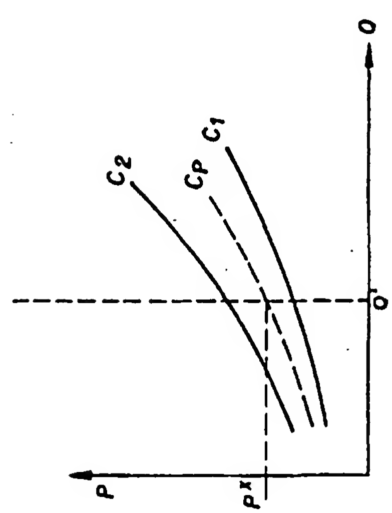

FIG. 5b

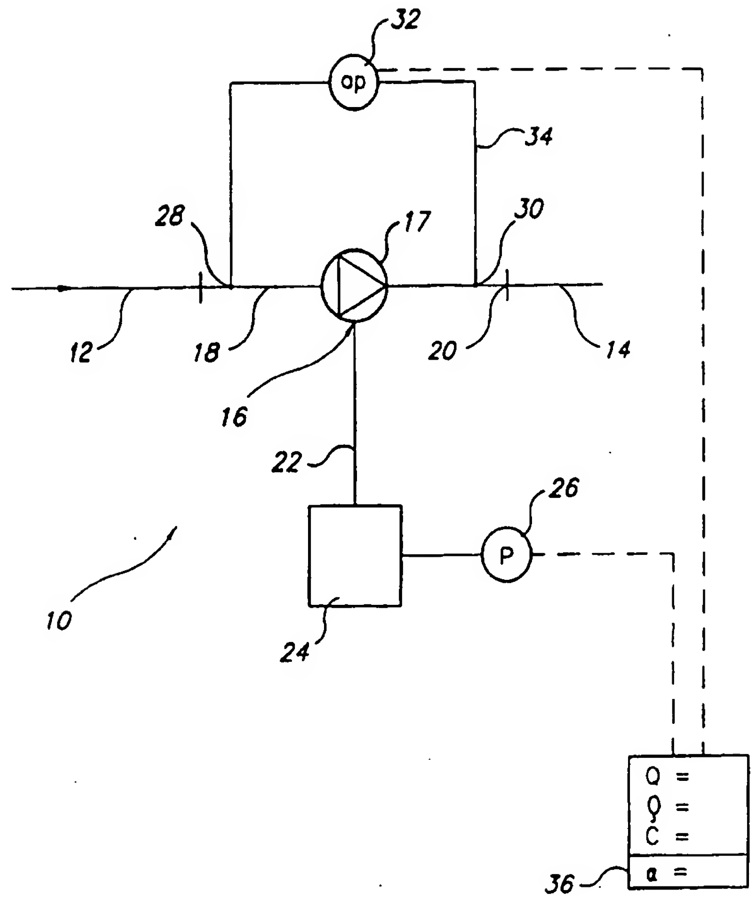

FIG. 7

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 96/00698

A. CLASSIFICATION OF SUBJECT MATTER

IPC6: G01N 9/00, G01N 11/00 // F04D 7/04
According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC6: G01N, F04D

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

SE,DK,FI,NO classes as above

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

WPI

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 5129264 A (JEROME A. LORENC), 14 July 1992 (14.07.92), column 2, line 49 - column 4, line 61, figure 1	18-34,37
A		1-17,35,36, 38
	--	
X	US 3453868 A (C.S. WILLIAMS, JR), 8 July 1969 (08.07.69), column 2, line 3 - column 4, line 14	27-30,35
A		1-26,31-34, 36-38
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[X] Further documents are listed in the continuation of Box C. [X] See patent family annex.

* Special categories of cited documents:
"A" document defining the general state of the art which is not considered to be of particular relevance
"E" ertier document but published on or after the international filing date
"L" document which may throw doubts on priority claim(s) or which is cited to establish the publication date of another citation or other special reason (as specified)
"O" document referring to an oral disclosure, use, exhibition or other means
"P" document published prior to the international filing date but later than the priority date claimed
"T" later document published after the international filing date or priority date and not in conflict with the application but cited to understand the principle or theory underlying the invention
"X" document of particular relevance: the claimed invention cannot be considered novel or cannot be considered to involve an inventive step when the document is taken alone
"Y" document of particular relevance: the claimed invention cannot be considered to involve an inventive step when the document is combined with one or more other such documents, such combination being obvious to a person skilled in the art
"&" document member of the same patent family

Date of the actual completion of the international search	Date of mailing of the international search report
10 April 1997	12 -04- 1997
Name and mailing address of the ISA/ Swedish Patent Office Box 5055, S-102 42 STOCKHOLM Facsimile No. +46 8 666 02 86	Authorized officer Gunnel Wästerlid Telephone No. +46 8 782 25 00

INTERNATIONAL SEARCH REPORT

International application No.
PCT/FI 96/00698

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	Derwent's abstract, No F2975 E/18, week 8218, ABSTRACT OF SU, 849051 (MOSCOW LIKHACHEV CAR WKS), 23 July 1981 (23.07.81)	27-31,36
A		1-26,32-35, 37,38
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X	Derwent's abstract, No 87- 55774/08, week 8708, ABSTRACT OF SU, 1242755 (GORKI WATER TRANSPT), 7 July 1986 (07.07.86)	27-30,35
A		1-26,31-34, 36-38
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A	NO 126706 B (BEN COWAN), 12 March 1973 (12.03.73), claims 1-3	1-38
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INTERNATIONAL SEARCH REPORT
Information on patent family members

04/03/97

International application No.
PCT/FI 96/00698

Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 5129264 A	14/07/92	NONE	
US 3453868 A	08/07/69	NONE	
NO 126706 B	12/03/73	NONE	